Comparison of ns vs ps Laser Assisted Vacuum Arc EUV Source

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Motivation

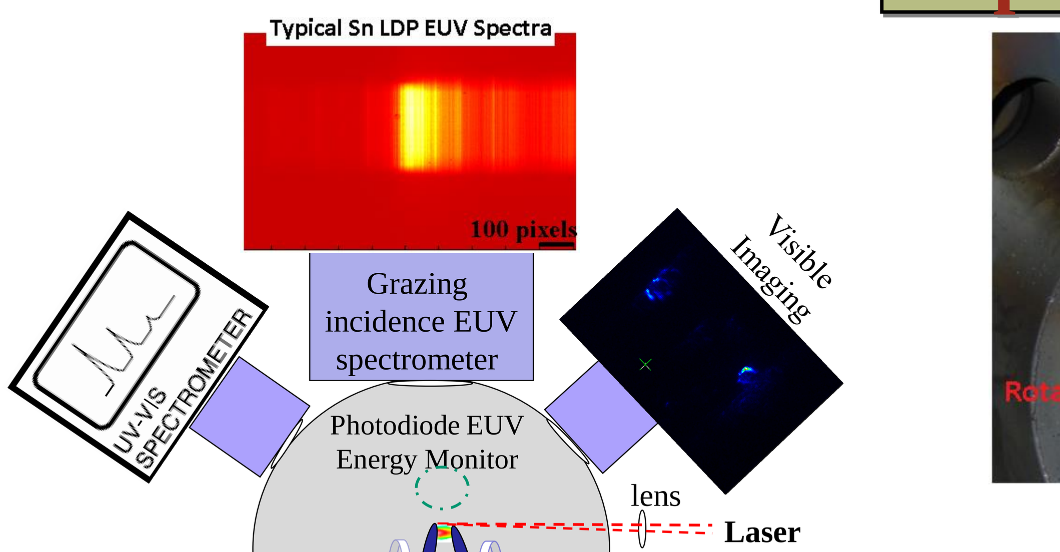
Plasma based EUV sources have been studied extensively to meet strict requirements on high power & brightness among others. Xe based Discharge-Produced Plasmas (GDPP) have a lower conversion efficiency (CE) and associated heat load problems. The motivation is to develop a hybrid Laser-triggered Discharge Plasma (LDP) for which: the electrode is regenerative and so erosion is reduced, it is laser-assisted so the required input power is reduced and, it is Sn based which has an intrinsically higher CE in comparison to Xe.

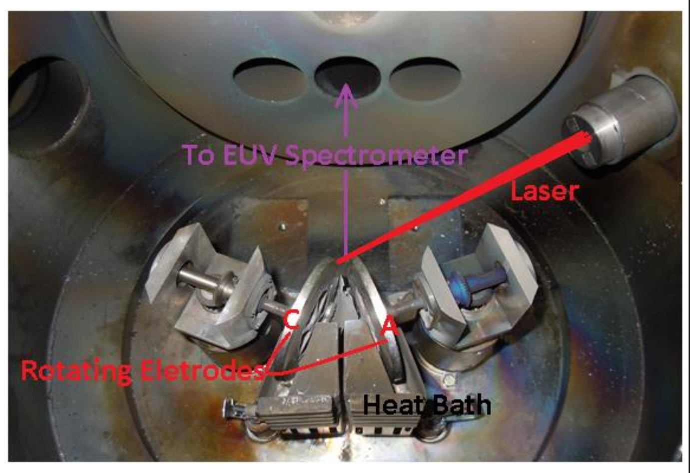
Introduction

• The aim of this work is to produce EUV photons from a discharge plasma formed by liquid **Sn** coated on rotating-wheel-electrodes. The Energy stored in the capacitors heats the Sn plasma to a high enough ionization optimum for EUV emission [1]. The discharge is triggered by localized ablation of the thin film with either a **~160ps or ~7ns, 1064nm Nd:YAG** laser. The laser spot size was experimentally determined to be ~520um, and the laser energy (LE) was varied from 1 to 100mJ, implying a power density range of ~3-300 GW/cm2.

• A comparison of the conversion efficiency (CE) was made, where the ps-triggering resulted in higher CE values compared to ns-triggering. As shown by a 2D-RMHD simulation code-Z*[2], the difference could mainly be attributed to the expanding plasma dynamics, where the ps-gives a somewhat collimated, smaller and hotter plasma and hence higher conductivity, which then facilitates the ohmic heating for an efficient EUV emission during the pinch.

Experimental Setup



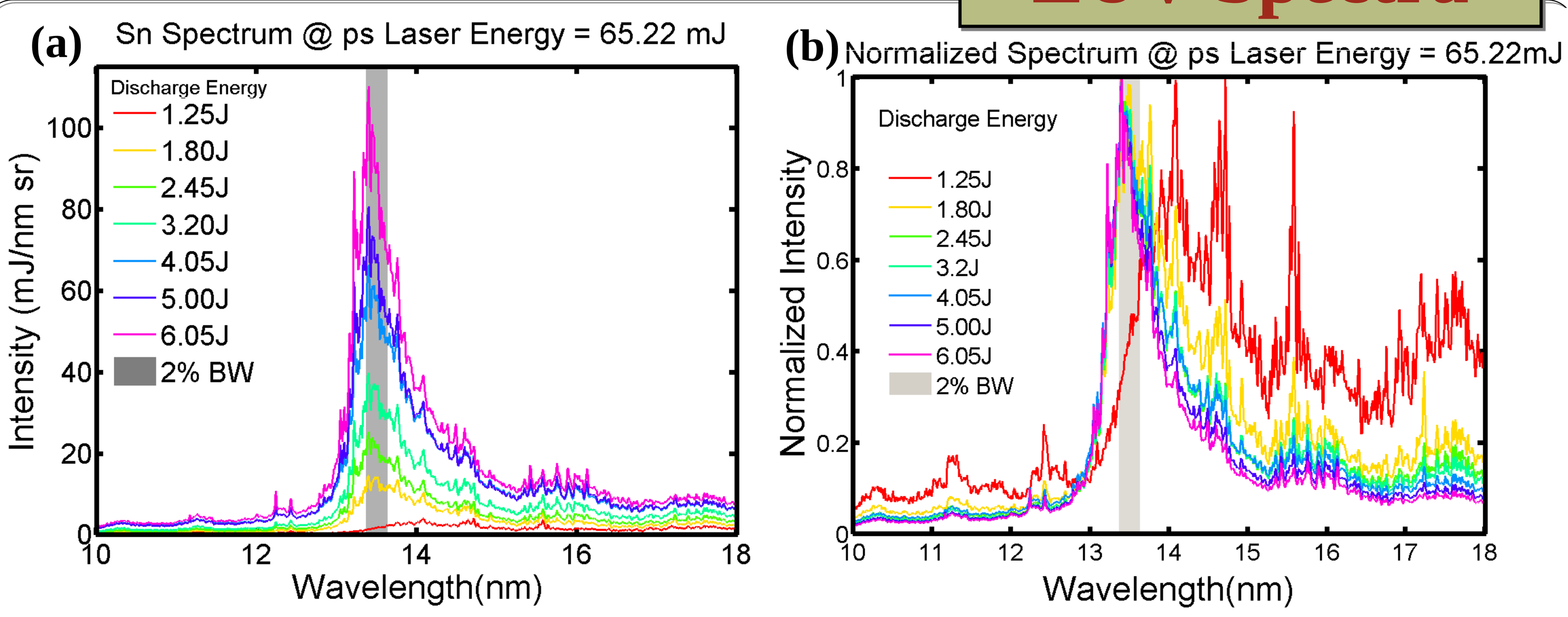


Trigger laser: ~160ps or ~7ns

Wavelength	1064 nm
Beam diameter	6 mm
Focal lens	33 cm
Energy	1 – 100 mJ

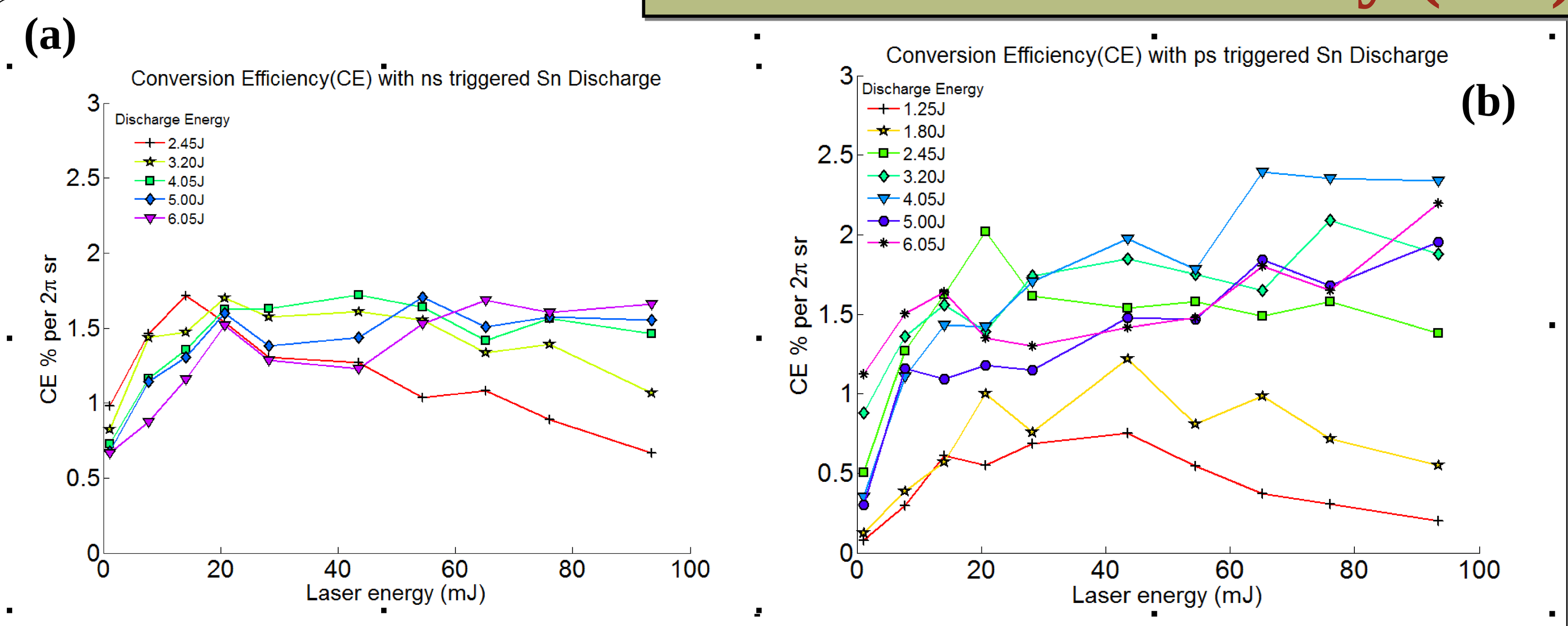
Capacitance	0.4 µF
Inductance	19 nH
Voltages	2.5 – 6 kV
Discharge Energy	1.25 – 7.2 J
Current	~20 kA at 4.5KV

EUV Spectra



The EUV spectra for ps-triggering show typical features of optically thin plasma above ~3.2J (a), and at lower discharge energy, the plasma is dominated by lower ion stages (b) [3].

Conversion Efficiency (CE)



The CE saturates at higher laser energy both for ns (a), and ps laser triggering (b).

References

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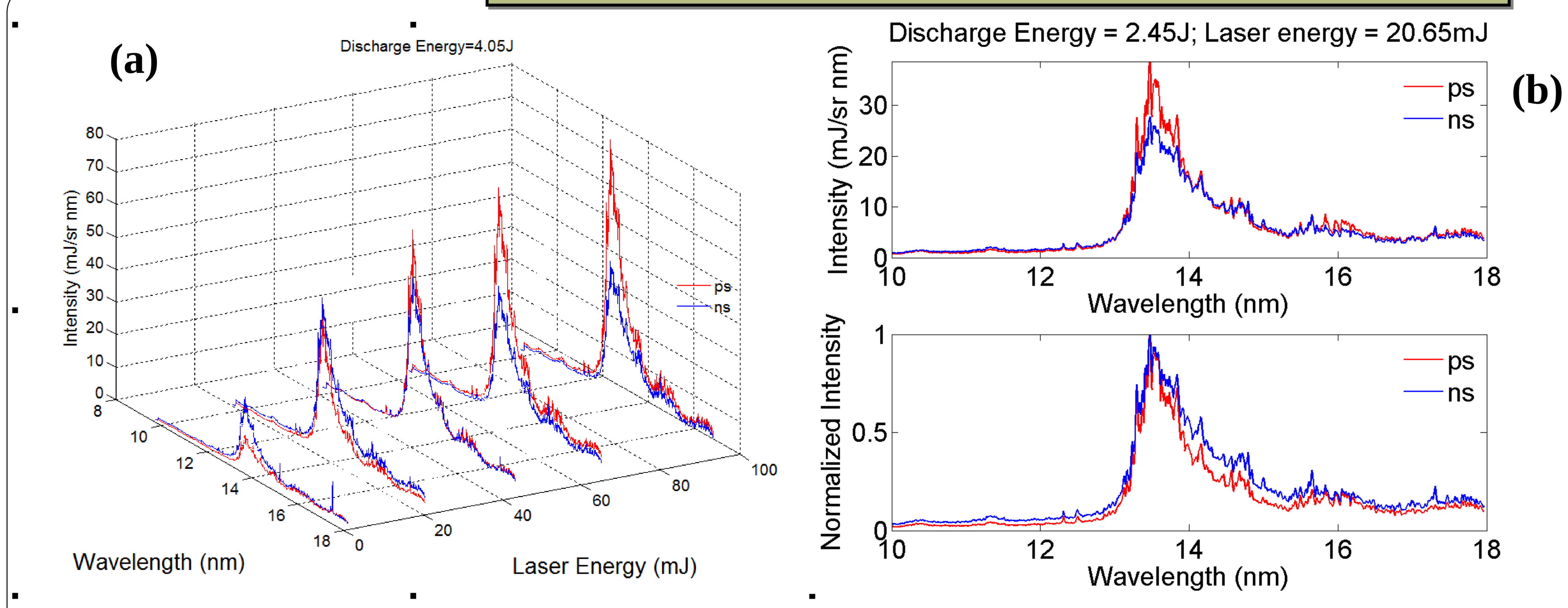
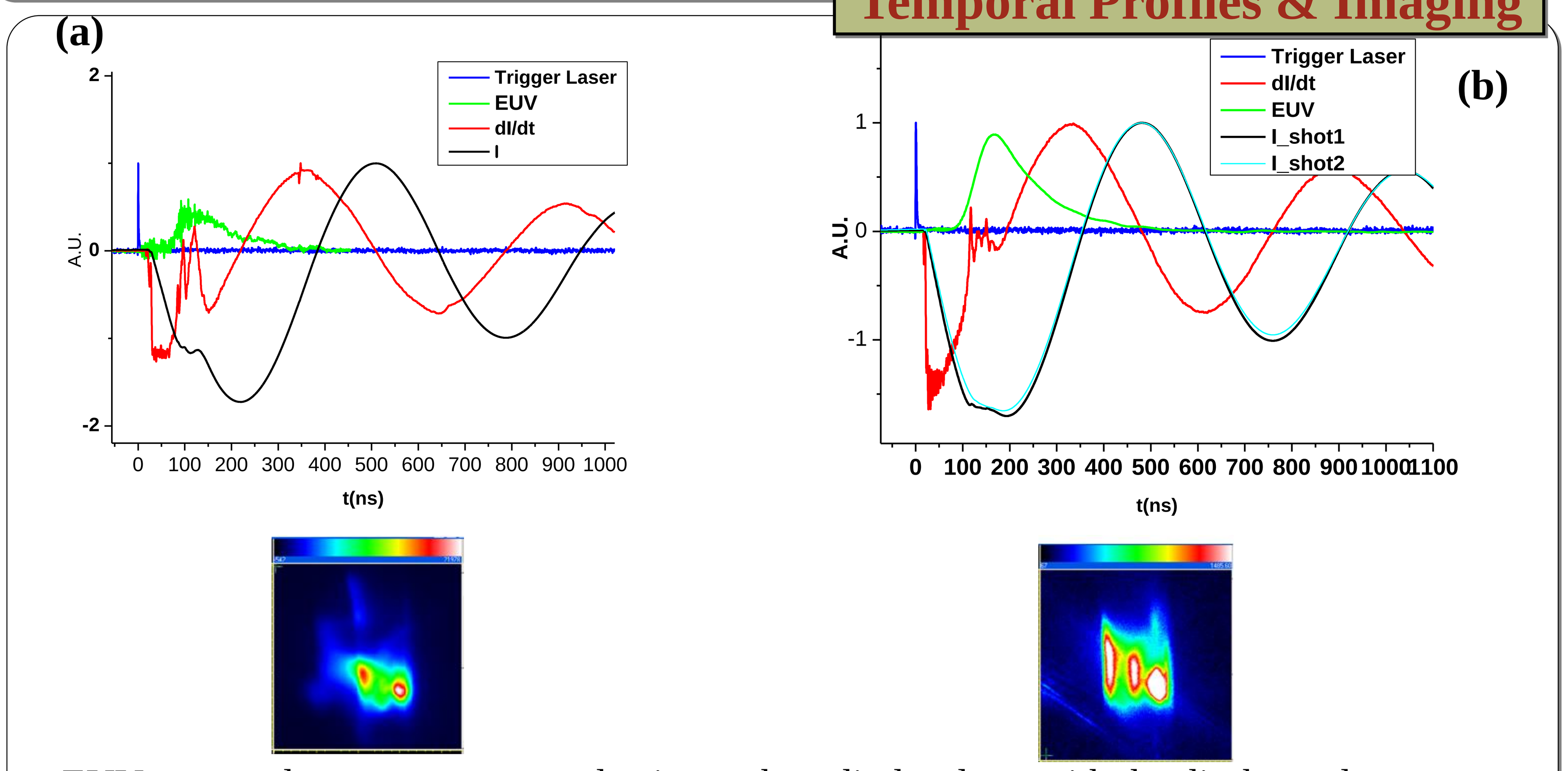
[2] S.V. Zakharov, V.G. Novikov, P. Choi, "Z*-code for DPP and LPP source modelling". EUV Sources for Lithography. Ed. V. Bakshi. SPIE PRESS, 2005. 223.
[3] P. Hayden. "Extreme Ultraviolet Source Development Using Laser Plasmas Containing Tin", PhD thesis, UCD, 2007.

ps vs ns EUV spectra



As laser energy increases, the EUV spectra (at fixed discharge energy), saturates quickly for ns triggering as seen in (a). Shown also in (b) are spectra for ps (red), and ns (blue) laser triggering, where the ps shows brighter & narrower spectral profile under similar conditions.

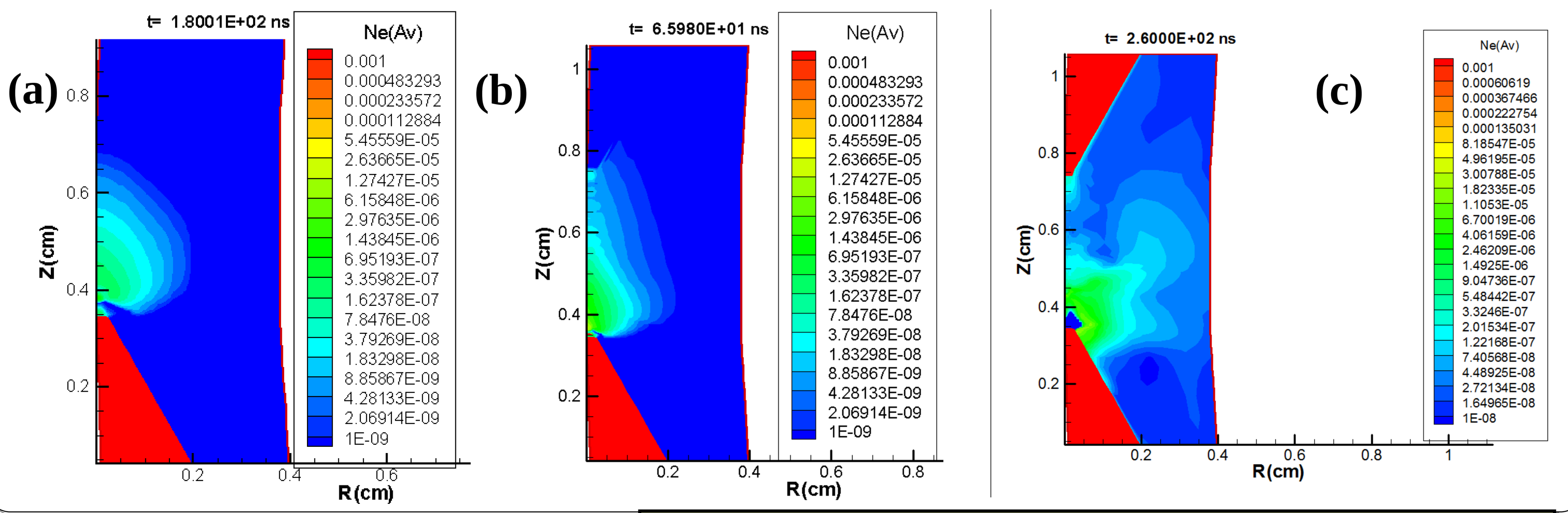
Temporal Profiles & Imaging



- EUV temporal response measured using a photodiode, along with the discharged current, measured using a Rogowiski coil. Pinching times earlier than I_{max}, resulted in reduced EUV (a), while EUV emission is optimum when pinch time matches I_{max} (b). The corresponding time integrated visible images captured in the wavelength range of 400 - 500 nm show the same trend.

Z* Simulation

The 2D RMHD simulation code Z* showing time evolution of plasma dynamics (a); a 30ns triggered (b) and 160ps triggered laser plasma. Shown on (c) is a compression phase typical for transient pinch effect.



Conclusions & Future work

- Picosecond-triggered Sn-based discharge produces a higher CE compared to that of nanosecond-triggered. As the laser energy was increased, the CE tends to plateau at approximately 2.4% for ps and 1.5% for ns laser triggering.
- With fixed discharge voltages but higher laser energies, the ps triggering produces brighter EUV spectra compared to those in the ns case.
- The ps-triggering also produces narrower spectral profile showing higher spectral purity.
- EUV emission is higher when the timing of the current maximum matches the pinching time, and this is mainly sensitive to the input laser energy.

Future Work

- Further investigation of plasma parameters to better understand the instability, these include:
  - Visible spectroscopy to extract plasma density & temperature.
  - Time resolved imaging, to understand the pinch dynamics & plasma size.
  - Lens scanning of laser power density.
- Reheating with second laser. For instance: trigger with short pulse (7ns or even 160ps), then couple longer pulse (30ns Nd:YAG or CO2) with varying delays and energies.
- Further simulation with Z-star and Cowan codes.
- Challenges: wheel wobbling during rotation, shot-to-shot instability and self-discharging.

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